

Final Report for AOARD 10-4139  
“Ion source development for a compact proton beam writing system”

15 August 2011

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**Abstract:**

During this contract period the PI has recruited a PhD student and a research fellow who have started working on this project. During the field trips to Delft University the team has gained valuable knowledge. Through this exchange the team has now a realistic design for the ion source test bench to be installed in Singapore in the coming year. At the same time the new proton beam writing beam line developed under grant AOARD 07-4017 has been further improved and with this new beam line focused proton beams down to  $16 \times 29 \text{ nm}^2$  have been achieved.

**Introduction: Current status**

To overcome the diffraction constraints of traditional optical lithography, the next generation lithographies (NGLs) will utilize any one or more of EUV (extreme ultraviolet), X-ray, electron or ion beam technologies for producing sub-100nm features.

Electron beam lithography (EBL), a candidate for direct-write technology at nanodimensions has extensively been investigated for the last four decades. However, high resolution lines and spaces in single step exposures for EBL are limited to about 20-30 nm levels due to proximity effects from high energetic secondary electrons initiating from adjacent and nearby features giving rise to structure broadening.

Perhaps the most under-developed and under-rated is the utilisation of ions for lithographic purposes. The three ion beam techniques, Proton Beam Writing (PBW), Focused Ion Beam (FIB) and Ion Projection Lithography (IPL) have the flexibility and potential to become leading contenders as NGLs [i]. Since the

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| 14. ABSTRACT<br><b>This is the final report of the first phase of a project to overcome the diffraction constraints of traditional optical lithography to utilize ion beam technologies to produce sub-100 nm features.</b>   |                                    |                                     |   |                                    |
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introduction of PBW in the Japanese governments road map for the nanotechnology business creation initiative (see appendix I) a large multinational corporation, Kobelco, has been pushing the development of compact accelerators for PBW applications. The Shibaura Institute of Technology (Tokyo, Japan) has recently received a 2M US\$ grant from the Japanese government to develop PBW. In our Centre for Ion Beam Applications (CIBA), Physics Department, National University Singapore ***we established sub 100 nm proton beam focusing for protons down to 35x75nm<sup>2</sup> [ii] and have produced 3D high aspect ratio walls down to 22 nm in HSQ [iii]***. The minimum obtainable feature size is expected to be in the nano meter range, due to the absence of proximity effects. In order to achieve nm sized features the proton probe has to be focused down to nm dimensions.

In CIBA we have been working on next generation systems for proton beam focusing. The success of a next generation PBW system depends on two main components: a **stable high brightness source of MeV protons** and a **high quality focusing lens system**. With the help of the US air force we have designed a new system for proton beam writing (AOARD 07-4017). The key characteristics are an improvement of the system demagnification. In initial experiments a beam has been focused down to 13 nm in x direction and 16 x 29 nm<sup>2</sup> in x and y direction, closely matching the beam optical calculations.

### Experiment: Test bench setup

In order to optimize the current RF ion source used in CIBA Singletron accelerator, we have been working on building a source test bench, with which we expect to improve the ion source brightness by about 10 times. The idea of the test bench is to provide the RF ion source gas feed in and voltages to run. Electron optical parts and other attachments are built into the test bench to measure the proton beam current, energy spread and brightness. The test bench schematics are shown in figure 1. A more elaborate test bench (Fig. 2) will be introduced after initial test with the simple test bench (Fig. 1)

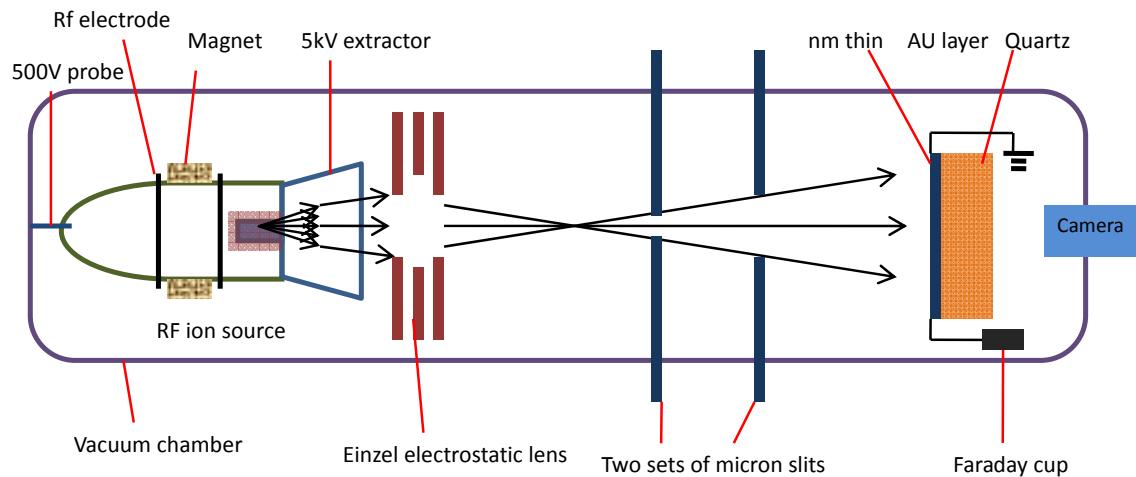


Figure 1. Simple test bench schematics for RF ion source testing.

The different ion sources will first be tested at low voltages of 5 – 10 kV. This will give fast and reliable information about the operation of these sources, therefore the high voltage dome (see Fig. 2) will only be designed when both ion sources work satisfactorily at low voltage in the test system.

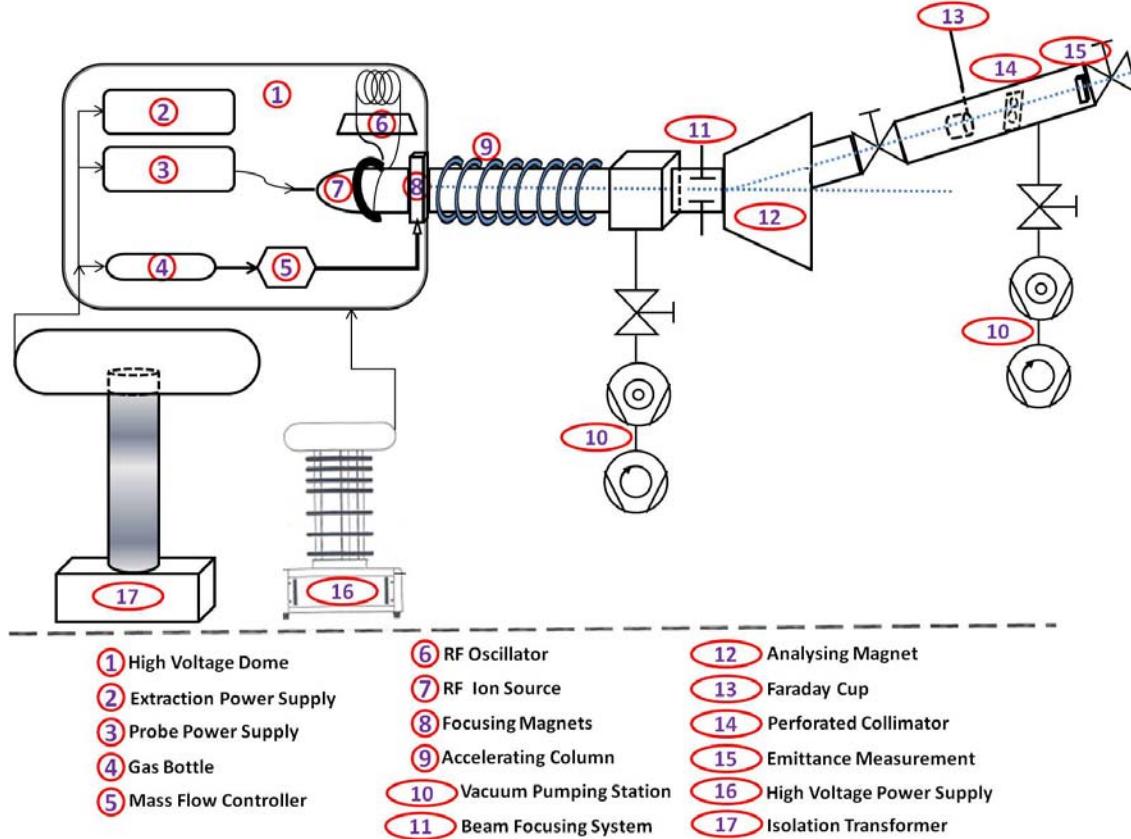


Fig. 2: The schematic diagram of Ion-Source Test Bench along with the low energy ion accelerator set-up.

This work is still on going and we expect to finish the building in next half year and start ion source experiments.

### The electron impact gas ion source test

A prototype Nano Aperture Ion Source (NAIS) gas chamber has been test by Prof Kruit, Prof Hagen and a PHD student is Delft for the last year. The experiments have shown with Argon gas feed in an ion beam current of 100-200 pA can be easily achieved. A first calculation shows the ion beam brightness is about  $3 \times 10^4 \text{ A}/(\text{m}^2 \text{ sr V})$ , which is in consistence with the theoretical calculation and comparable to a conventional Gallium Liquid Metal Ion Source (LMIS) for Focused Ion Beam (FIB).

To obtain a higher brightness ion beam, a new NAIS gas chamber has been developed in Delft. We have worked in collaboration with Delft on the new chip examination. The schematics of the setup are shown in Fig. 3. The thin membranes in

the NAIS gas chamber were milled by FIB to create feed in for gas and nano apertures for electrons and ions (Fig. 4). Electrons from a Schottky source bombard Ar gas particles in the NAIS gas chamber and ionize the gas. The positive ions are then extracted by the electric field from an extractor. The ion current is measured by a Faraday cup and pico-amp-meter.

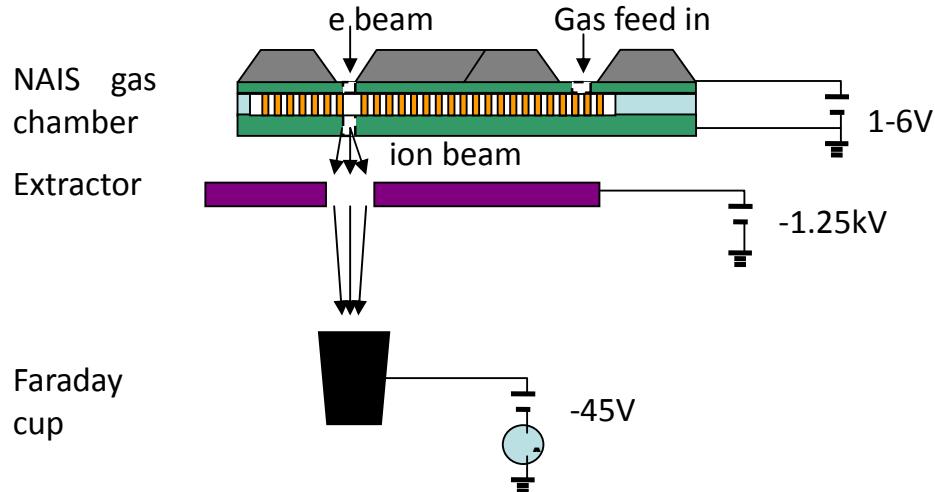


Figure 3. The schematics of the electron impact ion source test setup in Delft.

Fig. 5 shows the test setup with the NAIS chip mounted in the sample holder. The NAIS gas chamber is sitting in a SEM chamber, where electron beam is introduced into the gas chamber to bombard the gas particles for ionization. The induced ion beam current and brightness depend on a few parameters that can be varied for test, which includes the gas feed-in pressure, the bias voltage between the two membranes in the gas chamber, the electron energy and electron beam current. Currently the new NAIS gas chamber is still under inspection. We could modify the design and fabricate our new gas chamber for proton test.

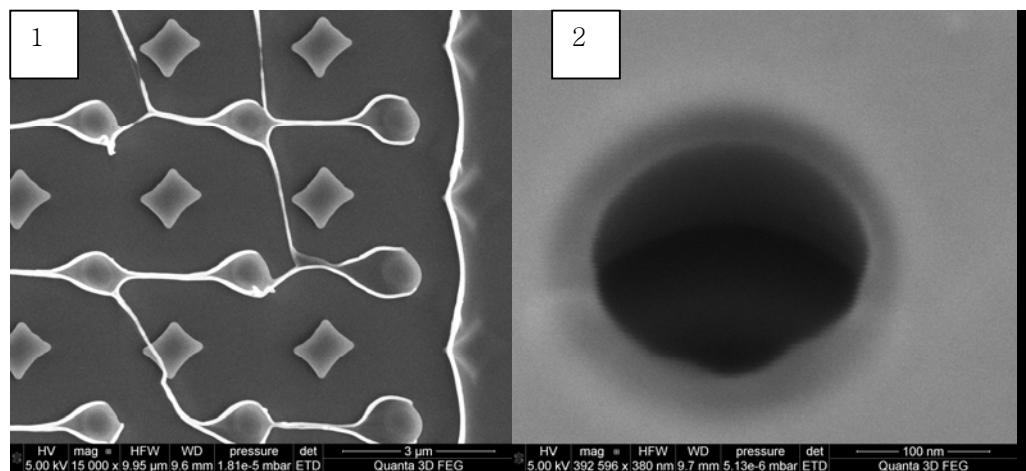


Figure 4. Scanning Electron Microscope (SEM) images of 1) nano apertures created by FIB milling for electron-gas impact; 2) gas entrance.

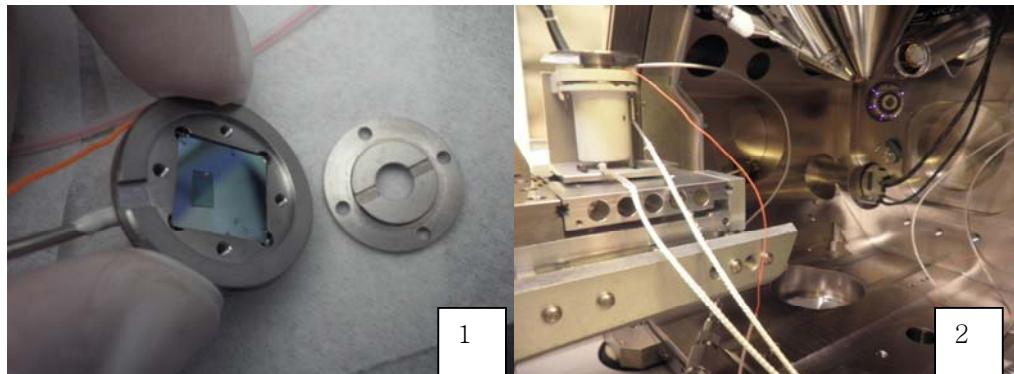


Figure 5. 1) NAIS gas chamber in sample holder; 2) gas chamber mounted in sample holder and sits on SEM stage in chamber.

### Results and Discussion:

Initial test in Delft have shown high brightness for the old electron impact chip design. The new chip design has potentially higher brightness but is still under investigations and will be tested further in the 2<sup>nd</sup> year.

In the coming year we plan to work on the following points:

- 1) Finalize a basic test set-up and optimize the current RF ion source system in CIBA. The electronics for this system will be developed and commissioned. This system will initially be tested at 5 kV. It will be designed to be compatible with higher energies of up to 300 kV.
- 2) Ar has shown high brightness with the new ion source design in Delft. Further tests in Delft are planned to measure the proton current, brightness and energy spread.
- 3) The optimum type of electron gun to ionize hydrogen gas in the new electron-impact ion source system will be evaluated for use in CIBA.

### List of Publications:

The system is still under development therefore publications are a bit early. But the PI has published several papers based on earlier grants from the US air force: **AOARD 07-4017 & AOARD 05-4037**

### Journal Publications:

- 1) The Singapore high resolution single cell imaging facility, Frank Watt, Xiao Chen, Armin Baysic De Vera, Chammika C N Udalagama, Ren Minqin, Jeroen A van Kan, Andrew A Bettiol, Nuclear Instruments & Methods in Physics Research Section **B** *in press*.
- 2) Proton beam writing nanoprobe facility design and first test results, J.A. van Kan, P. Malar, Armin Baysic de Vera, Xiao Chen, A.A. Bettiol and F. Watt, Nuclear Instruments & Methods in Physics Research Section **A** **645** (2011) 113-115.

- 3) Proton Beam Writing a platform technology for high quality three-dimensional metal mold fabrication for nanofluidic applications, J.A. van Kan, P.G. Shao, Y.H. Wang and P. Malar, in press Microsystem Technologies 2011 DOI 10.1007/s00542-011-1321-z.
- 4) Exposure parameters in proton beam writing for KMPR and EPO Core negative tone photoresists, M.D. Ynsa, P. Shao, S.R. Kulkarni, N.N. Liu, J.A. van Kan, Nuclear Instruments & Methods in Physics Research Section B *in press*.

**Conference presentations:**

1. **Invited Oral presentation: 2011** February at the Ion-beam Induced Nanopatterning of Materials, Bhubaneswar, India. Title *Nickel injection mould fabrication via proton beam writing and UV lithography for fluidic chip applications*
2. **Invited Oral presentation: 2010** July at the 8<sup>th</sup> Charged Particle Optics conference, Singapore. Title *Proton beam nano-probe technology and applications*
3. Oral presentation: June 2011 at the International Conference on Materials for Advanced Technologies 26/06/11 – 1/07/11, Singapore. Title *Next Generation Proton Beam Nano-probe Technology for Proton Beam Writing*.
4. Poster presentation at 36<sup>th</sup> MNE conference, September 2010, Genoa, Italy On “*Mold fabrication using PBW for nano fluidic and DNA analysis*”
5. Poster presentation at ICNMTA, July 2010, Leipzig Germany. On “*The Singapore next generation proton beam writing facility*”. This poster got an honourable mentioning at the conference.

**Appendix 1** See attached file.

**DD882:** See attached form.

**Publications:** See attached zip file.

**References:**

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- i *Ion beam lithography and nanofabrication: A review*, F. Watt, A.A. Bettoli, J.A. van Kan, E. J. Teo and M.B.H. Breese, **IJN** **4**, (2005), 269
- ii *The National University of Singapore high energy ion nano-probe facility: Performance tests*, F. Watt, J.A. van Kan, I. Rajta 1, A.A. Bettoli, T.F. Choo, M.B.H. Breese, T. Osipowicz, Nuclear Instruments and Methods in Physics Research **B 210** (2003) 14–20.
- iii Proton Beam Writing of 3D Nanostructures in Hydrogen SilsesQuioxane J.A. van Kan, A.A. Bettoli and F. Watt, *Nano letteres* **6**, (2006), 579.